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**M E M O R A N D U M**

DATE: November 1, 1993

REPLY TO
ATTN OF: Robert Cleveland, RFC SED, OET

SUBJECT: Items to be placed in Docket ET 93-62

TO: Secretary, FCC

The attached letter and two supporting documents from Professor Om P. Gandhi of the University of Utah, dated October 22, 1993, are relevant to the above-referenced docket that deals with new environmental guidelines for radiofrequency radiation. The Commission has proposed adopting new guidelines in our Notice of Proposed Rule Making in ET Docket 93-62 (FCC 93-142).

The originals plus four copies of this letter and the supporting documents are enclosed for incorporation into the docket record in this proceeding. This latest submission from Dr. Gandhi is in addition to a previous submission already placed in the docket record. If there are any questions please contact me at 653-8169.

ENCLOSURES

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October 22, 1993

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OFFICE OF ENGINEERING AND TECHNOLOGY

Mr. Thomas P. Stanley
Chief Engineer
Federal Communications Commission
Washington, D. C. 20554

Re: The Matter of "Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation," ET Docket No. 93-62

Dear Mr. Stanley:

I am writing as a researcher working in the area of environmental effects of radiofrequency radiation for over twenty years to present some data to you that may have a bearing on the above subject presently before the FCC.

## 1. Induced RF Currents

Enclosed herewith is a preprint of a paper by Tofani et al. (Appendix A) that gives the measurements and numerical calculations of currents induced in the human body close to FM transmitting antennas in the frequency band 90-104 MHz. This paper has been submitted for publication to the *IEEE Transactions*. In this paper we show that substantial currents would indeed be induced in a human for the MPE electric fields suggested in the ANSI/IEEE C95.1-1992 Safety Standard. I am aware of the opposition by some parties to the need for foot current measurements for frequencies above 50 MHz. The data presented in this paper is to the contrary. Since currents in excess of the RF safety guidelines could result for both controlled and uncontrolled environments, it appears to us to be important to measure not only the E- and H-fields, but also the induced currents up to the maximum frequency of 100 MHz recommended in the ANSI/IEEE C95.1-1992 Safety Standard. As shown in this paper, induced currents are also substantial up to at least 110 MHz. It may, therefore, be desirable to limit induced and contact RF currents for the entire FM band up to 108 MHz.

## 2. Low Power Devices/Exclusions

We have recently had an opportunity to evaluate rates of electromagnetic energy absorption (specific absorption rates or SARs) in the human head for ten typical cellular telephones capable of operating at a peak power of 0.6 Watts or 600 milliwatts in the frequency band 820-850 MHz. A summary of the results of this study is enclosed herewith as Appendix B. The peak 1 g SAR is on the order of 0.09 to 0.29 W/kg, depending on the telephone and the nature of its antenna.

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This is considerably smaller than 1.6 W/kg given for the uncontrolled environments in the ANSI/IEEE C95.1-1992 RF Standard. We are presently in the process of writing the details of this study as a possible publication in a peer-reviewed journal.

Even though similar studies are needed at higher frequencies because of the smaller antenna size and the concomitant localization of the applied power, the power limit prescribed in the ANSI/IEEE C95.1-1992 under exclusions for the uncontrolled environment is certainly quite conservative for the present-day cellular telephones operating at 820-850 MHz.

Sincerely,

Om Gandhi

OM P. GANDHI
Professor and Chairman

OPG:jk

Enclosures

APPENDIX A

# INDUCED FOOT-CURRENTS IN HUMANS EXPOSED TO RADIO-FREQUENCY EM FIELDS

S. Tofani(1), G. D'Amore(1), G. Fiandino(1), A. Benedetto(1),
O. P. Gandhi(2), and J. Y. Chen(2)
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## ABSTRACT

Because of the strong relationship of the foot currents to the highest SARs in the human body, limits on these currents have been prescribed in the ANSI/IEEE Safety Standard for frequencies up to 100 MHz. We have measured the induced currents passing through the human feet for nine subjects exposed to vertically polarized electric fields close to transmitting antennas in the FM band 90-104 MHz. The experimental results are in excellent agreement with the numerical values obtained using an anatomically based model and the FDTD method both for the average male height of 1.75 m and the tallest experimental subject of height 1.91 m. Currents in excess of the RF safety guidelines would result both for controlled and uncontrolled environments if the incident electric fields were purely vertical and of maximum values given in the safety guidelines. It is important therefore to measure not only the E- and H-fields, but also the induced currents up to the recommended maximum frequency of 100 MHz and perhaps for the entire FM/TV based up to 110 MHz.

Submitted to IEEE Transactions on Electromagnetic Compatibility.

# EVALUATION OF INDUCED FOOT-CURRENTS IN HUMANS EXPOSED TO RADIO-FREQUENCY EM FIELDS

## INTRODUCTION

Because of its relationship to electromagnetic power deposition (specific absorption rates or SARs) in the human body, determination of the currents passing through the feet has become an important parameter for assessment of radiofrequency (RF) hazards. Limits of the foot currents have therefore been recommended in the recently approved ANSI-IEEE Safety Standard [1] in addition to the maximum values of electric and magnetic fields. The maximum total current for both feet suggested in the safety guidelines is 200 mA and 90 mA for controlled and uncontrolled environments, respectively.

Several papers have previously reported on the theoretical and experimental evaluation of the currents induced in the human body for exposure to plane-waves and for leakage electromagnetic (EM) fields of RF dielectric heaters [2-7]. However, there is lack of experimental data on foot currents induced by RF EM fields for frequencies in excess of 50 MHz [2]. Since the induced currents for male adults have been found to diminish for frequencies in excess of the grounded resonance frequency of 40 MHz, the lack of experimental data has led some to question the need for foot current measurements up to 100 MHz recommended in the ANSI-IEEE Safety Standard [1]. The focus of this paper is to give the experimental data on the measured foot currents for exposure to EM fields in the important FM broadcast band 90-104 MHz and to compare this data with the induced current distributions using the existing numerical methods. The data show that substantial currents would indeed be induced in the human body for the electric fields suggested in the safety guidelines. Since these currents would be in excess of the induced current limits recommended in the safety guidelines if the incident electric fields were to be vertical, measurement of foot currents is indeed necessary for frequencies up to 104 and perhaps to 110 MHz to ensure that the current limits in the safety standard are not exceeded.

EXPERIMENTAL MATERIALS AND METHODS

Foot currents were measured in outdoor electromagnetic environments characterized by the presence of multiple-source, multiple-frequency EM fields produced by antennas transmitting radio programs in the FM broadcast band (90-104 MHz). The antennas were made of vertical dipoles.

For measurements we have used a stand-on current dosimeter developed at the University of Utah[2], which consists of a polyethylene sheet of thickness 6 mm that was sandwiched between the copper plates of size 30 x 30 cm, placed in series with an RF milliammeter. The human body induced current through both feet to ground was determined by having a person stand on the top copper plate, the bottom plate being placed on the ground over an additional copper sheet of 50 x 50 cm to improve the grounding effect.

To evaluate the foot current induced in a human body exposed to multiple-source multiple-frequency EM field, we have made a spectral analysis of foot current connecting a spectrum analyzer (model HP 8562A) directly to the two copper plates of the dosimeter, whose impedance is 6 $\Omega$ at the considered frequencies.

The foot-current dosimeter was calibrated in the laboratory to evaluate its response versus amplitude and frequency of the current. The calibration has been made injecting in the dosimeter a known current produced by signal generator HP 8656B. The experimental set up for this calibration is shown in Fig. 1.

In the calibration curve shown in Fig. 2 the dosimeter reading as a function of the frequency, for different amplitudes of the injected current, are given. From this figure we can see that the dosimeter response is almost independent (within 5 percent) of the frequency in the considered frequency range. It can be observed also that the meter reading is accurate (within 5 percent) at 30 and 50 mA, while the current is increasingly overestimated by the meter above 50 mA reaching an overestimation of 11 percent at a current amplitude equal to 90 mA.

The total current evaluated from data obtained using the spectrum analyzer was compared with the total current measured by the dosimeter. To increase the accuracy we accepted only data in agreement between the two measurement systems.

Foot current was measured for nine subjects having different heights and areas A of the ankle sections. For each measurement point and frequency we evaluated the parameter $F_\nu = I_\nu/E_z$ where $I_\nu$ is the foot current at a fixed frequency $\nu$, and $E_z$ is the vertical component of the electric field.

The vertical component of the electric field was measured following the procedures reported in [8].

## NUMERICAL COMPUTATIONS

The procedure used for numerical computations has been described in detail in several of our earlier publications [3-6] and would therefore not be given here. For the present computations we have used an anatomically based model of the human body where the tissue compositions have been prescribed for each of the subvolumes of the body or cells of dimension 1.31 x 1.31 x 1.31 cm. As previously described [6], the tissue compositions were obtained from the anatomical cross sectional diagrams of the human body [9]. This model consisting of 134 layers has a height of 175.5 cm and weight 69.6 kg. Without changes in the human anatomy this model can be used to obtain scaled models with slightly different heights and cross sectional dimensions, respectively. By changing the cell size $\delta_z$ in the vertical (z-) direction from 1.31 cm to 1.425 cm, the height of the 134 layer model can for example, be increased to 191 cm to correspond to the height for the tallest of the experimental subjects. Similarly we can increase the cell size for the cross sectional planes $\delta_x = \delta_y$ from 1.31 cm to 1.546 cm to obtain the single-ankle cross sectional area A represented by 28 cells to be 66.9 $cm^2$ which once again, corresponds to the ankle cross sectional area for this 1.91-m tall individual who participated in the experiments.

For calculation of the induced electric field components we have used the well-established finite-difference time-domain (FDTD) method which has also been described in our earlier papers [3-6] and many other publications in the literature. As described previously [6] we have used the internal E-fields to calculate the local vertical (z-directed) current densities $J_z$ which were then used to obtain the vertical currents induced for the various layers. Consistent with the experimental conditions, we have considered the grounded models for the numerical computations. This was done to assess the worst case exposure of the individuals and also in recognition of the fact that shoe-wearing conditions do not result in substantial reductions (less than 15-20 percent) of the foot currents for frequencies in excess of 30 - 40 MHz [2].

## RESULTS AND DISCUSSION

In Fig. 3 we give the measured data as a function of frequency. Curve A gives the mean data for all nine subjects which had an average height of 1.75 m while curve B gives the data for the tallest of the subjects who had a height of 1.91 m. In Figs. 4 and 5 we give the calculated induced current variations for models of height 1.75 m and 1.91 m, respectively, for a vertically polarized incident field $E_z = 1$ V/m (rms) at frequencies varying from 90 to 110 MHz. In Table 1 we compare the experimentally and numerically determined values of $F_V$ at various frequencies. The agreement between the experimental and numerical values of $F_V$ is excellent.

We can see that the mean values of $F_V$ for the various subjects decreases with frequency, ranging from 4.46 to 3.45 in the frequency range 90 to 104 MHz. For a maximum permissible electric field value of 61.4 V/m given in the ANSI/IEEE safety guidelines [1] for the controlled environments, this will imply an induced current of 212-274 mA which is in excess of the 200 mA limiting value that has been recommended in the safety guidelines for these environments. Similarly for the maximum permissible exposure of 27.5 V/m in uncontrolled environments, the induced currents of 95-123 mA will also exceed the limiting value of 90 mA for these exposure conditions. For the tallest individual of height 1.91 m the currents will be even larger and on the order of 134 -149 mA in the frequency band 90-100 MHz for the uncontrolled environments. Both of these values are in excess of 90 mA suggested as the current limit in the ANSI/IEEE safety guidelines.

## CONCLUSIONS

Both the experimental data and the numerical calculations point to the need for induced foot current measurements for frequencies up to 100 MHz or perhaps through the entire FM/TV band up to 108-110 MHz. From the results presented in this paper it is obvious that substantial currents may indeed be induced in the human and that these currents will be in excess of the ANSI/IEEE limits of the foot currents if the incident fields were vertical and relatively uniform over the extent of the human body.

## ACKNOWLEDGEMENT

Gandhi and Chen's work on this project was supported by National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina (USA) under Grant ES -03329.

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Fig. 1. The experimental set up for calibration of the dosimeter. The current is injected in the dosimeter by the two copper plates shown at the left of the dosimeter itself, which is connected via coaxial cable to the spectrum analyzer.

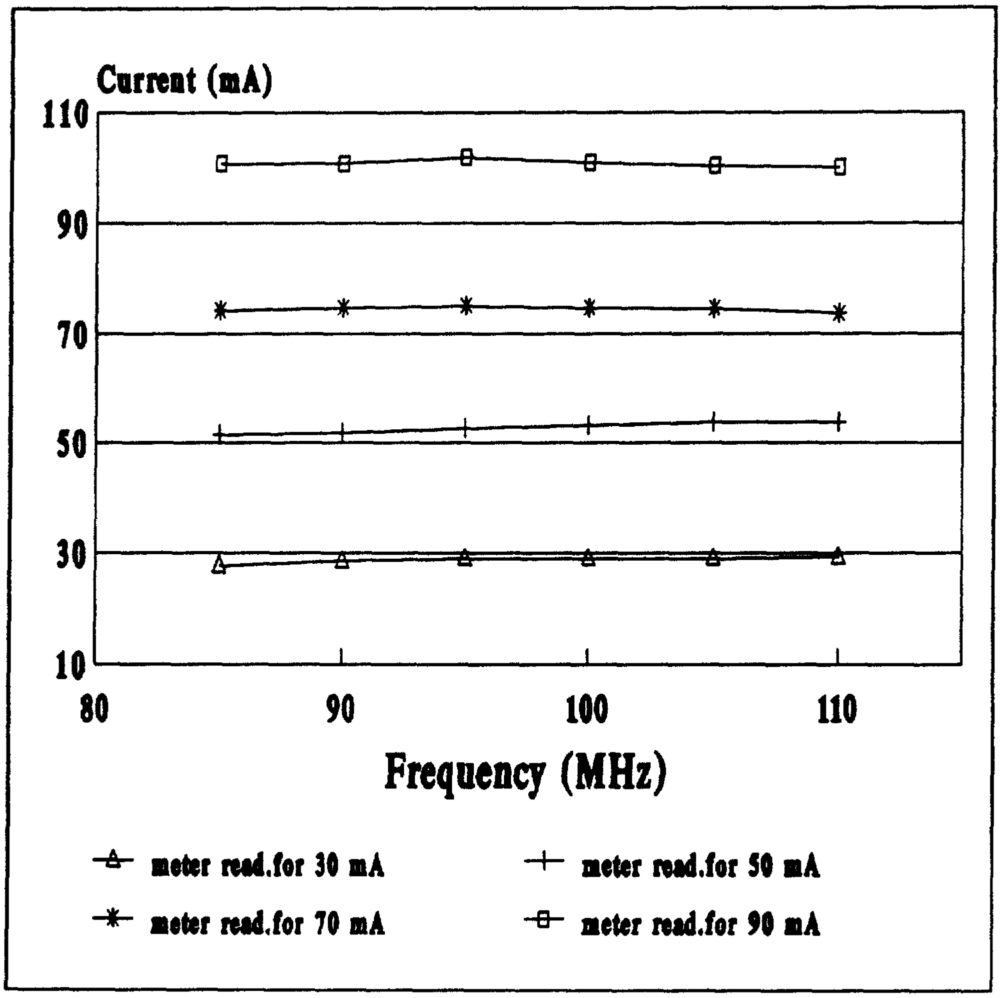


Fig. 2. Dosimeter reading as a function of frequency for four different amplitudes of the injected current.

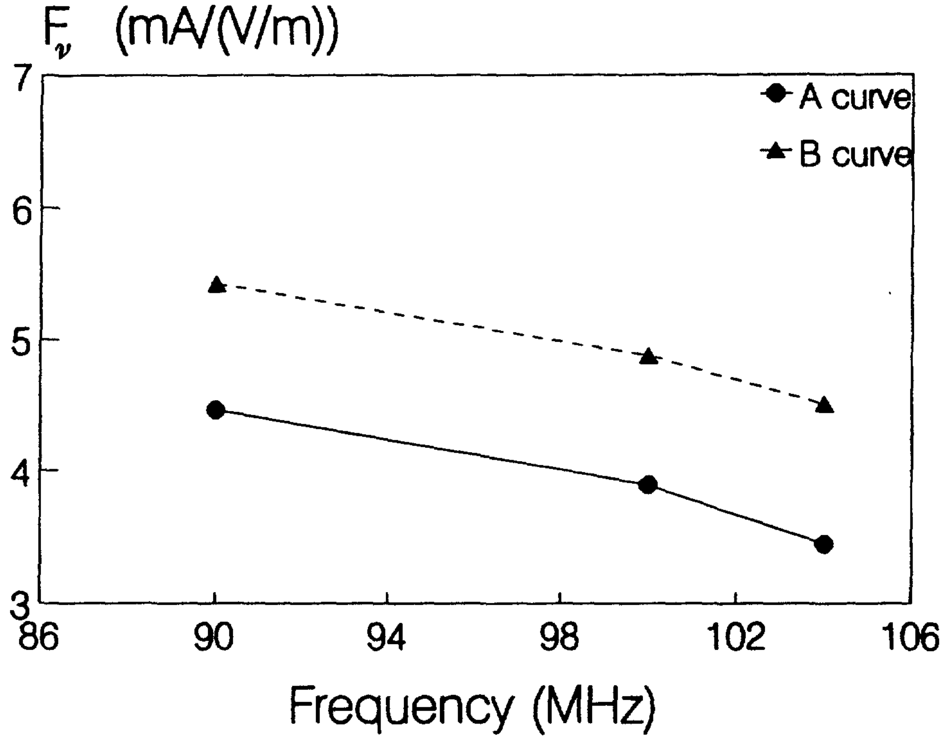


Fig. 3. Experimental foot currents for grounded subjects as a function of frequency; A curve shows the mean data for all nine subjects with an average height of 1.75 m; B curve shows the data for the tallest subject who had a height of 1.91 cm.

Table 1. Comparison of the experimental and numerical values of $F_v$ at various frequencies for human subjects of height h.

| Frequency MHz | Experimental $F_v$, mA/(V/m) | | Numerical $F_v$, mA/(V/m) | |
|---|---|---|---|---|
| | h = 1.75 m | 1.91 m | 1.75 m | 1.91 m |
| 90 | 4.46 | 5.42 | 4.38 | 5.11 |
| 95 | - | - | 4.10 | 4.90 |
| 100 | 3.90 | 4.87 | 3.97 | 4.64 |
| 104 | 3.45 | 4.45 | 3.85 | 4.35 |
| 105 | - | - | 3.84 | 4.28 |
| 110 | - | - | 3.78 | 3.88 |

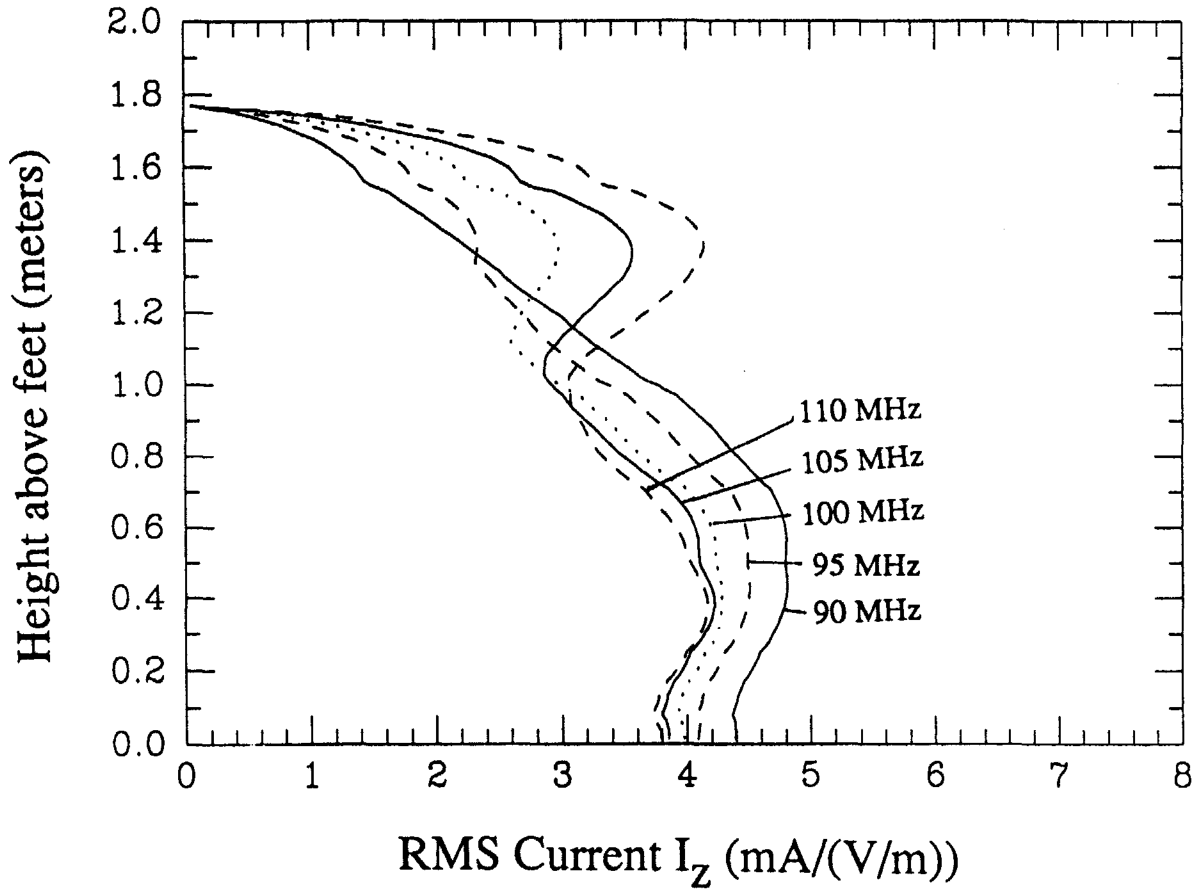


Fig. 4. Induced RF current variations for a grounded 1.75 m-tall anatomically based model of the human body for the frequency band 90-110 MHz.

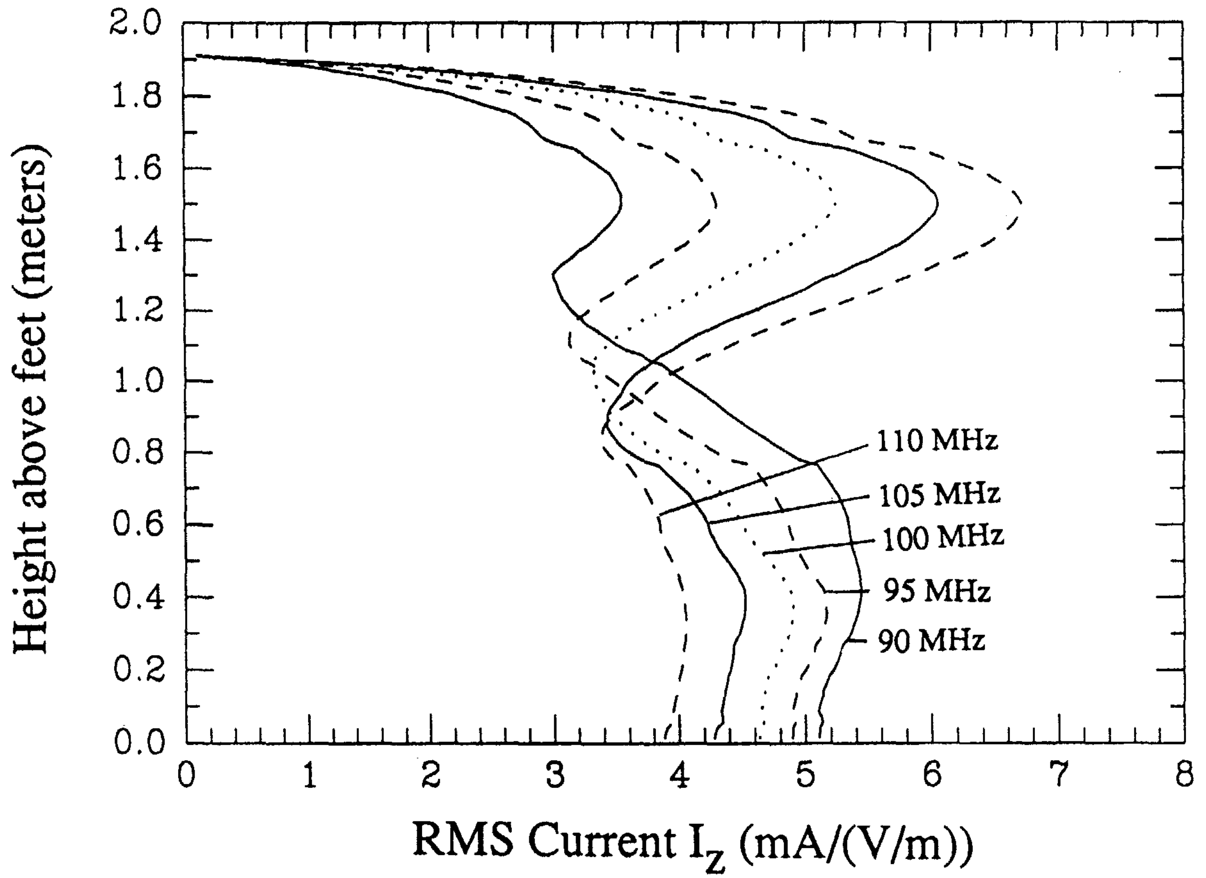


Fig. 5. Induced RF current variations for a grounded 1.91 m-tall anatomically based model of the human body for the frequency band 90-110 MHz.

Om P. Gandhi 8/2/93

# ELECTROMAGNETIC ABSORPTION IN THE HUMAN HEAD FOR CELLULAR TELEPHONES

## Summary

We have used both computational and experimental techniques to obtain mass-normalized rates of electromagnetic energy absorption (specific absorption rates or SARs) in the human head for ten cellular telephones from four different manufacturers. For numerical computations we have used a newly developed high-resolution model of the human body that was obtained from the magnetic resonance imaging (MRI) scans of a male volunteer. For this model, anatomically based tissue properties were prescribed for each of the subvolumes or "cells" of dimensions approximately $2 \times 2 \times 3$ mm or 11.7 milligrams of the tissues. The well-established finite-difference time-domain computational technique was used to calculate the electromagnetic fields and SARs for all the regions of the body with particular emphasis on head, neck, shoulders, and the upper torso for cellular phones held against the ears. Because of the proximity of the upper ear to the radiating antenna, most of the electromagnetic absorption occurs for the upper cartilage-dominated part of the ear with a rapidly diminishing SAR for the nearby tissues in the head. For the tissues in the head, the SARs diminish rapidly to 1 percent of the peak SAR values for the upper ear at a depth of 3-5 cm from the side of the head against which the phone is held, and are relatively miniscule elsewhere.

We have verified the highlights of the numerical calculations by means of a head-shaped experimental model made of tissue-equivalent materials simulating the electromagnetic properties (dielectric constant and electrical conductivity) of skull, brain, muscle, eyes, and ears developed for use at the cellular telephone frequency of 835 MHz. For this heterogeneous model, the SARs were obtained experimentally by measuring the radio frequency electric fields that were created by each of the telephones.

Based on the detailed studies of the three telephones, the highlights of the results are as follows:

1. For a maximum possible antenna power of 600 mW, the power absorbed by the head and neck, depending on the telephone and the nature of its antenna, can vary from 23 to 65 mW. The power absorbed by the whole body is not much higher and can vary from 33 to 78 mW.
2. The peak SAR averaged over any 1 g of tissue defined as a volume in the shape of a cube occurs for the volume involving the upper ear. The peak 1 g SAR is on the order of 0.09 to 0.29 W/kg, depending on the telephone and the nature of its antenna. This is considerably smaller than the 1.6 W/kg suggested in the ANSI/IEEE C95.1-1992 safety guidelines. If the 1 g of tissue in the form of a cube is all taken to be the inside tissue such as for the brain, the peak 1 g SAR is even smaller. For the various telephones we have found the peak values of the SARs for any 1 g of tissue, all in the brain, to be between 0.04 to 0.17 W/kg.
3. The whole-body-average SAR can be obtained by dividing the total power absorbed by the weight of the body. For total-body absorbed powers on the order of 33 to 78 mW, a whole-body-average SAR on the order of 0.5 to 1.1 mW/kg is obtained. Once again, this is a factor of 80 to 160 times smaller than the whole-body-average SAR of 0.08 W/kg or 80 mW/kg considered to be acceptable by the ANSI-1992 safety standard.

Another factor to be considered is the averaging time of 30 minutes prescribed in the ANSI safety guideline at the cellular telephone frequency of 820-850 MHz. The time-averaged values of the whole-body-average and spatial-peak SARs would, therefore, be smaller than the above quoted values if the cellular telephone is in operation for only a fraction of time in any given 30-minute period.